# Current Developments in Cost Accounting/Performance Measuring Systems for Implementing Advanced Manufacturing Technology

by

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# ABSTRACT

Much has been written over the last decade regarding the various obstacles to implementation of computer integrated manufacturing (CIM). The general concensus in this literature is that traditional financial justification procedures based on internal rate of return (IRR) or short payback periods are perhaps the greatest barriers to adopting new manufacturing technology. This review focuses on much of this literature that has been published or released within the last 24 months. A section reviewing the evolution of cost analysis methods is provided and followed by arguments from various researchers/authors as to why they believe traditional cost accounting measures are either inappropriate or improperly applied. The review then describes various modifications to existing cost accounting methods in addition to some new ideas, as prescribed by these researchers/authors. The project concludes with a case study that demonstrates two of the surveyed methods.

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# 1 INTRODUCTION

Much has been written over the last decade regarding the various obstacles to implementation of computer integrated manufacturing (CIM). The general concensus in this literature is that traditional financial justification procedures based on internal rate of return (IRR) or short payback periods are perhaps the greatest barriers to adopting new manufacturing technology. The literature surveyed touches on a variety of related topics including the evolution of cost analysis techniques, recommended modifications to traditional accounting methods, as well as several state-of-the-art approaches. These new/modified techniques are all intended to more adequately represent and justify new technologies.

This review focuses on literature published or released within the last 24 months (with several exceptions). A section reviewing the evolution of cost analysis methods is provided and followed by arguments from various researchers/authors as to why they believe traditional cost accounting measures are either inappropriate or improperly applied. The review then describes various modifications to existing cost accounting methods in addition to some new ideas, as prescribed by these researchers/authors. The project concludes with a case study that utilizes two of the surveyed methods.

# 2 PROBLEMS WITH TRADITIONAL ACCOUNTING METHODS

## 2.1 Evolution of Cost Analysis Methods and Automation

To fully understand some of the problems associated with trying to justify new technologies with old cost accounting methods, it is important to first examine the evolution of cost analysis methods and automation. Baron [1] explains that prior to 1950, automation was primarily hard automation, such as machines and conveyor material movement, employed to solve the cost and mass production problem. Return on investment (ROI) justification was straightforward: labor dollar savings paid back the investment.

In the 1960s, following the lead of the financial community (which employed the computer to ease the burdensome tasks of accounting and auditing), manufacturing began using the latest computer technology to solve the material availability problem. Baron [2] points out that justification wasn't ROI, but rather assuring timely shipments by having the proper material available to build the product.

More applications to solve other problems soon followed. Labor standards and tracking reduced costs (but not enough to justify the computer resource on an ROI basis). Purchasing applications helped assure material availability and thereby improve schedules. Wherever computer technology was employed by manufacturing it was to overcome roadblocks for the scheduling and building of products - not the bottom line ROI.

Automation using mainframe computers received a boost in the early 1970s for three reasons:

1. Cost savings expectations had risen through experience with computer methods.

2. Between 1969-74 a disproportionate number of manufacturing middle management personnel retired (opening the door for younger, higher risk-taking managers).

3. The production planning applications and computers they ran on were becoming old, burdensome, and costly to maintain.

In the 1970s, a second generation of computerized production planning, Manufacturing Resource Planning (MRP II), was implemented. But even with the cost savings history, justification for these new systems was based on solving the problems of the old, costly systems.

In the 1980s, hundreds of companies began to adopt Just-in-time (JIT) and CIM techniques with goals of zero defects, lot size of one, no work-in-process inventory, and space compression, as part of a competitive strategy. Hronec [12] remarks that the closer a plant gets to true JIT production, the greater the gap between the type of information traditional cost acounting systems provide and the type management actually needs to run and control a JIT/CIM factory.

Hronec [12] lists some of the changes that have driven manufacturers' need for a new cost management system:

- The supply of immediately required inventory at the line eliminates central storage and physical barriers on the factory floor.

- The decrease of direct labor and the increase of knowledgeable workers on the plant floor creates a need for training and new incentives.

- Vendors and suppliers are no longer viewed as adversaries but now become a manufacturer's partners in profit, and costs can be driven out of raw materials and purchase parts.

- Receiving and shipping are no longer segregated from production.

- Paperwork is radically reduced.

## 2.2 Changes in Cost Behavior Patterns

A manufacturer's cost behavior patterns change dramatically under these new manufacturing techniques, says Hronec [12]. These changes include: decreased inventory levels, increased fixed costs of production, decreased variable costs, and blurring of direct-indirect cost designations. Traditional cost accounting systems have not taken into account these fundamental changes and cost behavior pattern changes in the new manufacturing environment. Hronec [12] elaborates by stating that traditional cost accounting systems do not support the management decision process because they have three inherent characteristics (shown below) that are out-of-date and therefore irrelevant in a CIM or JIT operation.

1. Traditional accounting systems typically allocate costs to products based on direct labor hours or dollars. The ratio of labor cost to product cost has decreased significantly since the early 1900s. As the relative cost of labor continues to decline, the percentage of overhead increases.

2. Traditional cost accounting systems encourage the

wrong thing - the buildup of inventory.

3. Current productivity reporting has little or no relationship to how strategic decisions are actually made.

Michaels [17] explains that these characteristics are perpetuated by the fact that many managers perceive that costs are black or white - they are either direct labor or material or overhead. As a result, too many modernization efforts focus only on reducing declining direct labor costs, although many significant improvement opportunities are not direct labor related. To plan and justify CIM investments properly, it is necessary to focus on indirect labor improvements and to challenge the process by which overhead costs are allocated to products.

## 2.3 Specific Problem Areas

### 2.3.1 Improper Definition and Allocation of Overhead

An example of what happens when overhead costs are improperly allocated is described by Nuccio [23]. Under the traditional method, the overhead cost for a particularly expensive piece of factory equipment may be charged against all products made in the plant - even if the expensive machine is used for only one of the factory's products. That may cause a company to understate the product's cost, or to overstate the cost of goods that aren't made using the expensive equipment.

Dhavale [9] writes that this approach of computing each product's share of the overhead cost is totally inadequate in an automated manufacturing setting. In conventional job shops, the overhead measured as percentage of total manufacturing cost is relatively small (10 to 40%) compared to direct labor and direct material. However, the overhead becomes the largest of the three components in a CIM environment because of the higher depreciation costs of numerical control (NC) machines, computers, micro- processors, automated transportation systems, etc.

In addition, says Dhavale [9], the direct labor requirements of a CIMS are substantially lower than those of a job shop. This helps to push the percentage of overhead even higher, to the range of 70 to 90% of total manufacturing costs. Not only are the direct labor hours reduced in a CIMS, but they are no longer easily identifiable and assignable to the jobs. Because of the lot size flexibility in a CIMS, this makes it extremely difficult for operators to allocate their time correctly to different units of different jobs being processed simultaneously on different NC machines under their control.

Dhavale [9] is in agreement with Nuccio [23] when he remarks that it is totally inappropriate and unfair for a low cost machine to subsidize the jobs manufactured on the expensive machine, because those jobs are allocated artificially low overhead.

### 2.3.2 Improper Consideration of Subjective Criteria

Noble [22] states that another drawback of traditional techniques (i.e., payback period, return on investment (ROI) and net present value (NPV)) in justifying CIM projects is that they ignore subjective criteria. For example, CIM investments are often measured against a status quo alternative. Status quo assumes that there will be no change in market share or revenues if CIM is not implemented. However, in a highly competitive environment, it is likely that one or more competitors will automate to gain market share. Their ability to respond quickly to new opportunities allows them to gain market share at the expense of less flexible competitors.

Benefits that are difficult to quantify, such as improved quality and increased flexibility, are generally not included in traditional cost analyses. This, in effect, assigns intangible benefits a value of zero. However, inventory, rework, and customer dissatisfaction represent significant costs that will be reduced by CIM. Time horizons or time spans used for cash flow analysis are typically set at three to five years. CIM projects take several years to fully implement, so benefits do not become financially apparent for two to three years, but may continue for up to ten years. If the time horizon is short, CIM benefits are excluded from the analysis. Time horizons of ten to twelve years are generally required to compare CIM with long-term alternatives.

### 2.3.3 Artificially High Hurdle Rates

Additional problems are caused by the fact that many companies set artificially high hurdle rates (between 15 percent and 40 percent) to allow for risk and to ensure that investments yield the highest return. However, the real cost of capital is about 8 percent. In addition, high hurdle rates severely discount long-term benefits. Using high rates of return focuses the company's long-term strategy on maximizing short-term profits (Noble [22]).

### 2.3.4 Persistence of the Status Quo

Bennett, et al [4] also believe that traditional accounting procedures are inappropriate to justify CIM, and for many of the reasons previously discussed. They also remark that a company must consider the consequences of not acquiring an automated project. For example, if it doesn't get a CAD/CAM system, will it lose some current customers to competitors who have the systems? This potential loss of future sales should not be overlooked when analyzing automated projects. Many companies have used it as an important incentive to acquire automated projects, but it is hard to quantify. Vollmann [32] concurs with these ideas and provides similar discussion.

O'Guin [24] asserts that because of the continuing acceleration of new technological innovation, American management can no longer tolerate the mistaken assumption underlying conventional justification procedures - that with or without new product or process investment, market share will remain constant. He strongly believes that management's faith in the persistance of the status quo to be the main cause of America's present manufacturing trade deficit (O'Guin [24] provides a list of examples to support his position).

### 2.3.5 Insufficient Benefit Analysis

According to Sullivan, et al [31], high hurdle rates, comparison with status quo, and insufficient benefit analysis are the main reasons that traditional investment evaluation methods do not adequately justify new manufacturing technologies. Regarding insufficient benefit analysis, the authors remark that, in a sense, companies seem to be incorporating subjective risk adjustments into the analysis twice - once through the use of a high discount rate and then again by omitting many of the benefits that are difficult to quantify. When high hurdle rates are combined with an incomplete accounting of benefits, few strategic projects will be adopted.

Nanni, et al [21], provide similar discussion regarding benefit analysis in addition to problems with the way overhead is traditionally treated. The authors also believe that the way in which detailed cost accounting data are aggregated does not lead to meaningful understanding of many managerial problems, particularly those which are cross-functional in nature. One major firm estimates that, even in well-run organizations, less than 75% (more likely 50%) of the costs in a particular area are actually controlled by a single department. That is, engineering may account for less than 50% of the costs of product design, quality control less than 50% of the cost of maintaining quality levels, and so on. When shared costs are ignored and responsibility for particular outcomes is assigned to specific organizational units (thus implying that the results are due to the activities of that unit alone), the ability to match costs with benefits is lost. In many cases, management tends to ignore the fact that minimizing costs within departments does not guarantee minimization of overall costs (Nanni [21]).

Sullivan, et al [31] provide a list of subjective (but very real) benefits that can be obtained from proper implementation of technology improvements in the factory. The list includes higher product quality, reductions in inventory, reductions in floor space, reductions in throughput time, reduction in product development lead times (faster response to the market), and increased learning about the process. Described in the next section is an expert system co-developed by Sullivan that captures the subjective nature of many benefits in a decision.

According to O'Guin [24], many decision makers wrongly fail to invest in new technology/products because their financial projections (using traditional techniques) and analysis ignored the potential customer-perceived quality improvement of a new technology. Experience shows that customers select a particular product from a group of competing products not because it necessarily has the lowest cost or price, but because it has the highest "value." Each customer evaluates his perception of price and performance to pick the product with the highest marginal return. Therefore, if a company improves customer-perceived quality, it increases value and therefore customer desirability and sales (O'Guin [24]). A discussion on how to better define customer-perceived quality and thereby develop an improved cost accounting system is provided in the next section.

### 2.3.6 Managers' Misperceptions

Research by Gold [10] indicates that some of the problems in justifying new technologies can be attributed to misperceptions of managers both in evaluating capabilities before adoption and in appraising results after substantial use. The author writes that regarding estimation of productive *efficiency gains, decision makers have a tendency to*:

- Underestimate the time needed to get an innovation functioning effectively.

- Overestimate average utilization rates.

- Overestimate gains in efficiency.

- Concentrate on the prospective physical inputs and outputs of innovative hardware without paying sufficient attention to what kinds of additional contributions may be required from the staff.

- Ignore the probable costs of gaining labor acceptance.

Gold [10] also outlines some of the common mistakes that managers make in their cost and profit estimates:

- Overestimation of expected reductions in wage costs.

- Lack of recognition that new technologies may require more costly materials because they need to satisfy more distinctive dimensional and quality specifications.

- Too much concentration on the expected cost benefits of the innovation when it is fully utilized, overlooking the market fluctuations that ensure periods of underutilization. (Even if existing output is concentrated on the newest facilities, the firm must still bear the costs of underutilizing older equipment.)

- Assumption that company will be able to convert all reductions in unit costs to profits. (Ignores the likelihood that lowered prices and increased sales will compel competitors to lower their own prices, even if they have not achieved comparable cost savings.)

Gold [10] provides additional discussion as to why managers have problems evaluating results after substantial system use. One such problem is that postinstallation reviews seldom attempt to determine the causes of deviations from expected results. Such findings are urgently needed if similar errors are to be minimized in the future. Another problem is the fact that most companies make a single appraisal six to twelve months after the project's completion. These early appraisals often yield overly optimistic findings: the evaluators make generous allowances to offset actual shortcomings on the assumption that these are attributable to temporary problems such as excessive maintenance, inadequate labor experience, or underutilization because of incomplete integration with adjacent operations.

The author then offers some ideas for improving predecision estimates, as well as evaluating and improving results after installation. These ideas will be touched on in the next section.

### 2.3.7 Other Flaws

McDougall [16] has investigated cost accounting systems at many different firms and writes that all the systems based on traditional measures suffer from at least three flaws:

1. Engineered standards or approved budgets are by definition indicators of "good enough" manufacturing performance. This can cap learning. The companies have competitors who define "good enough" only in terms of unattainable ideals (zero defects, zero inventory, zero lead time, etc.). They may never stop learning.

2. These measures focus at the wrong levels. They relate the performance of individual departments and managers to internal objectives, not to the organization's competitive goals. By so doing they elicit behaviors designed to make the departments and managers look good on paper, rather than to make the organization look good in its customers' eyes.

3. These systems report only on cost. Cost is not a competitive variable: the customer never sees the company's cost.

McDougall's ideas for identifying a new performance measurement system are covered in the next section.

In light of the vast number of articles being published regarding justification of computer system technology, it is apparent that old accounting measures need to be modified and new measures developed.

## 2.4 Are Corporate Decisions Based on "Faith" Alone?

Kaplan [14] suggests that corporate decisions to purchase new computer systems have been based on incorrect and incomplete data. He contends that, in the past, such decisions have typically been an "act of faith" without being sensitive to the realities of CIM. How widespread is this position? Bennett, et al [3] report of a 1986 national survey of Fortune 500 firms on the topics of manufacturing, distribution, and finance. A variety of ideas were offered by the 67 financial executives who responded to the survey. While not every executive would agree with Kaplan that decisions regarding resource commitments to technology were based on "faith" alone, most did agree that changes were needed.

Michaels [17] reports that surveys of Fortune 500 and smaller companies indicate that many cost systems, typically developed many years ago, have not kept pace with changes in the manufacturing environment. The author also remarks that these cost systems need to be modified or replaced by entirely new systems. Financial, and not technical limitations, are impeding the implementation of advanced manufacturing technologies like FMS, CIM, artificial intelligence and robotics in the United States (O'Guin [24]).

Some of the most recent ideas regarding modified, as well as new cost management systems are outlined in the following section. A case study is included.

# 3 NEW METHODS FOR CIM COST JUSTIFICATION

## 3.1 CIM Readiness

Before a company can even begin to consider the financial aspects of CIM implementation, it must test its overall readiness for CIM. To do this, Sheridan [30] recommends that a company compare its operation against a checklist devised by Dr. George Mendenhall, president of SBI Corp., Ft. Wayne, Indiana. One precondition for a successful CIM implementation, Dr. Mendenhall stresses, is "enterprise-wide commitment" to making it work. His checklist helps a company determine if it has that enterprise-wide commitment.

Once a company decides that it is ready for CIM, various cost accounting techniques are available to the company as it attempts to represent and financially justify the investment. Some researchers believe that only minor modifications to traditional cost accounting procedures are required to more adequately represent and justify CIM. Others are of the opinion that completely new methods are needed. A variety of these ideas are discussed in the following pages.

## 3.2 Some New Performance Measures

Hronec [12] writes that implementing CIM technology can be adequately justified when new ways to measure costs and performance are implemented - and modified as the plant floor is modified. The author suggests that some performance measures for engineering (for example) might include:

- Total lead time from engineering concept through start of production for new products.

- Percentage of products that meet target cost objectives after one year of production.

- Average number of engineering change notices generated internally for a product in the first year of production.

- Average days to process an engineering change notice from request through production implementation.

- New equipment uptime during first year of production.

- Raw material yield in first year of production.

A new cost management system would include equivalent performance criteria for other crucial production functions and activities. Each company's cost management system would be tailored to its specific strategies and operations.

As previously discussed in Section 2, O'Guin [24] believes that developing a better definition of customer-perceived quality will lead to an improved cost accounting system. The first step, O'Guin writes, is to establish an impartial team to document for each major product line its customer-perceived quality. The team first documents how the product's non-price attributes satisfy customer needs and expectations. Then the company's customers and distributors are interviewed and surveyed for their needs, expectations and perceptions.

The team, using cluster analysis, can develop customer profiles, classifying customers by what attributes each group seeks. From the surveys, the team develops weights reflecting the relative importance of each attribute. For each product attribute, the customers rate the company's product superior, average or inferior. After normalizing the survey results for each attribute into percentages, the "average" percentages are dropped out and the "inferior" percentages are subtracted from the "superior" percentages. Multiplying this difference with the attribute's weight produces the attribute's score. The scores are then added to define the product's quality rating, which can range from a low of -100 to a high of +100.

By relating specific performance measures to each attribute, such as portability to weight, noise to operating decibels, ease of maintenance to the annual maintenance cost, etc., a company can not only monitor its own quality over time, but also its relative quality. Through this quantification of relative customer-perceived quality, a company can estimate market share change and include relative quality changes in the financial justification of a new project (O'Guin [24]). The article includes further discussion on the remaining steps required to carry out the complete justification in addition to an illustrative example.

### 3.3 How Should Overhead be Computed?

Dhavale [9] suggests that problems in justifying CIM systems using traditional accounting methods are due to inaccurate overhead and provides the following pointers about how overhead should be computed:

- Stop using plant-wide overhead pools; instead, accumulate overhead cost into smaller pools. Ideally, overhead should be pooled for each machine center. Recent studies report many companies continue to use plant-wide or large department-wide pools.

- Stop using direct labor hours as the allocation basis for overhead cost. Consumption of the overhead items in a CIMS does not depend on the number of direct labor hours used. In fact, that relationship is inversely proportional. The continued use of direct labor hours will totally distort the overhead allocation. Instead of direct labor hours, machine hours would be an appropriate allocation basis, especially when the overhead costs are pooled by the machine centers. Again, studies report that companies continue to use direct labor hours to allocate overhead costs.

- Direct labor hours and their cost are no longer significant in most CIMS. The direct labor cost should be made part of the overhead. Then the manufacturing cost would have only two components, direct material cost and transformation cost. The transformation cost includes all other manufacturing costs, including direct labor cost. Changing the name from overhead to transformation cost would be advisable to eliminate misconceptions about the overhead cost. Furthermore, the term "transformation cost" correctly describes the nature and purpose of the cost pool.

Accurate product costing data will help managers make better decisions about product mix and efficient use of expensive manufacturing equipment so that their companies can prosper in highly competitive manufacturing markets (Dhavale [9]).

### 3.4 Net Present Value

According to Goodwin, et al [11], what we need for anlayzing automation investments is a technique that:

- takes the time value of money into account,
- lets you compare one automation option against another, and
- quantifies all cash inflows and outflows from the investment.

The authors believe that the relatively common net present-value (NPV) cost-benefit analysis comes closest to satisfying the preceding criteria. This technique, described in most engineering economy texts, compresses into a single dollar value all future inflows and outflows over the projected life of the system. The dollar figure lets you compare investments and make the best decision for spending your investment dollars.

The two main issues in using this technique are 1) selecting the proper discount rate (Harvard researcher Robert Kaplan cites 8.5% as the historic average total return on common stocks (Goodwin, et al [11]) and 2) translating seemingly intangible benefits into cash inflows. The paper provides a tabular listing of various intangible benefits including comments on their respective degrees of measurability. These comments are all well taken, but as to their overall value, we need only refer to the intangible benefit "increased market share", as an example. The table tells only that this benefit is "not easily quantified," without any suggestion as to how one might even attempt to quantify this benefit. The same scenario holds true for other intangible benefits such as "upgraded employee skill levels" and "improved corporate planning."

In a later article, Bolland, et al [6] (Eric Bolland (analyst) and Sally L. Goodwin (president) of Micro-Managers Inc. co-authored references [6] and [11]) again recommend use of NPV cost benefit analysis. They go on to add that a third important issue in the analysis is the lifetime of the equipment. Also provided is a general example comparing the results of using three different methods (payback period, average rate of return and NPV) to select an alternative.

### 3.5 Expected Value Analysis

Noble [22] offers some insight into the issue of measuring intangible benefits (while providing some concrete guidelines for developing a new cost management system). He states that some benefits can be estimated using functional experts to develop assumptions on the improvements that can be expected. (The Delphi Method (described by Canada, et al [7]) can be a very effective technique for developing realistic expectations). Other benefits cannot reasonably be quantified, such as increased flexibility or the value of real-time information. However, according to Noble [22], expected value analysis can sometimes be used to estimate potential savings.

Expected value analysis uses probability and weighted averages to estimate cost savings for functional areas that are difficult to quantify. Potential cost reduction is estimated using several reasonable ranges (i.e., 0-5 percent, 5-10 percent, etc.) and a midpoint is calculated for each range (2.5 percent, 7.5 percent, etc.). Using experts, the probability of occurence is estimated for each range. The current cost for the function is multiplied by the midpoint to estimate average cost reduction for that range. The cost reduction for each range is then multiplied by the probability of occurrence for that range to obtain the estimated savings. The sum of the estimated savings is the expected value of cost savings (Noble [22]).

One very effective option for measuring "intangible" benefits, as recommended by Vasilash [32], is the utilization of an accounting firm-based integrator. He explains how Andersen Consulting's Systems Integration Center (Chicago, IL) has been extremely successful in putting dollar values on benefits that were assumed to be intangible.

### 3.6 Combining Quantitative and Qualitative Methods

According to Noble [22] (who supports the use of a combination of quantitative and qualitative methods to compare alternatives), three types of justification should be performed to adequately assess both strategic benefits and risks:

1. Strategic justification
2. Cost justification
3. Benefits analysis

For strategic justification, three types of evaluation are suggested:

- **Strategic planning.** Strategic plans ideally should be developed via a nominal group technique-type setting with active participation (described by Canada, et al [7]) by top management from all functions. Objectives are to: evaluate corporate strengths and weaknesses; develop a five-year company mission and goals statement; determine manufacturing strengths and areas for improvement; develop manufacturing performance goals; and evaluate CIM's capability to meet goals and objectives.

- **Market assessment.** Market assessment evaluates customer needs and industry trends to determine how CIM would affect market share and position for each product line. The goals are to: determine whether customers want the improvements offered by CIM; assess how competitors are currently positioned in terms of the improvements CIM would offer; determine areas of opportunity that CIM may offer in new products and services; evaluate technological trends in the industry; and evaluate CIM's impact on each product line's market position and share.

- **Functional analysis.** A top-down functional analysis is required to: identify operations that do not add value to the product; identify opportunities for improvement through automation; evaluate current technologies and their applicability to manufacturing oeprations; determine information required to plan, monitor, and control operations; and analyze trade-offs and benefits of alternive technologies.

If the project is strategically justified, cost justification's goal is to ensure that the project's return equals or exceeds the opportunity cost of relevant alternatives. Costs should be broken down in as much detail as possible to compare alternatives. Costs often overlooked in justification calculations include: indirect labor, inventory, quality control and floor space. Cost projections should include a realistic assessment of all potential benefits. The techniques previously described (Delphi Method and Expected Value Analysis) can sometimes be used to generate these projections. Once a company is satisfied with its projections, traditional accounting methods can be used for cost justification.

Finally, benefit analysis can be used to assess CIM's overall ability to meet strategic objectives. Noble demonstrates a graphic method for evaluating the relative value of each strategic alternative. This method (similar to the Weighted Evaluation Method described by Canada, et al [7]), consists of a checklist of strategic objectives, each of which has been assigned a relative weight based on the importance of each objective in achieving the company's strategic plan. Then alternatives are rated on ability to meet corporate objectives. Objectives are rated from 1 (not met) to 10 (fully met) for each alternative. Ratings are multiplied by the relative weight to obtain a score for each objective, and summed to obtain a total score. Total scores indicate the relative merits of each alternative in meeting strategic objectives (Noble [22]).

Bennett, et al [4] prescribe a very similar approach for justifying investment in automated technology, summarized in the following five steps:

1. Determine the long-term strategic goals of the firm and an enabling manufacturing strategy.

2. If automated equipment is to be acquired, list all expected benefits and costs associated with the automated equipment.

3. Quantify those items listed in step 2 that can be estimated with a reasonable degree of accuracy.

4. Calculate internal rate of return or net present value and payback for those items quantified in step 3. These calculations may justify acquisition. If not implement step 5.

5. Quantify the remaining benefits and costs using a team approach and probability analysis. Calculate internal rate of return or net present value and payback to determine if project is now financially acceptable.

Michaels [17] suggests yet a third very similar approach for justifying CIM. He writes that the first and most important task is to define manufacturing's role in your overall competitive advantage strategy and recommends the use of value-based planning to address strategic repositioning and marketplace factors. The article includes a detailed explanation of this procedure. Essentially, value-based planning is a technique that provides a financial framework consistent with investor and top management criterion of cash-stream timing rather than short-term profits.

The next step, says Michaels [17], is to define an "as is" model of business processes, representing the value chain of activities in your business and including all administrative activities. The idea here is that reducing the total cost of a process reduces the cost of a product. Each process in the value chain model is next assigned to the appropriate improvement program. Doing this identifies the scope of activities to be evaluated in developing an improvement program project portfolio and in completing the cost-benefit analysis (Michaels [17]).

The article provides additional detailed discussion on the remaining steps in the analysis: develop cost and performance baselines; identify and design the portfolio of projects associated with each improvement program; and perform cost-benefit analysis and economic justification. This last step entails analyzing the causes or "drivers" of costs in order to predict "to be" cost and performance accurately. These parameters are then used to quantify each program's impact on cost displacement and revenue improvements. The article includes several excellent graphical illustrations.

### 3.7 Decision Support Systems

Some researchers are exploring the use of various linear and goal programming applications to assist in making economic justification decisions. Chandra, et al [8] demonstrate how the Leontief input-output model (a mathematical representation of a system in which a linear transfer relation is assumed to exist among all the interrelated parts of the system) and linear programming can be used to determine performance measures of a flexible manufacturing system (FMS) for the economic justification of the system. The performance measures include: the total number of units processed within a specified time interval at each machining center; the number of acceptable components produced within a given time interval; and the average number of transfers between machining centers for each component. The first two performance measures are used to estimate the productivity of the system and the costs associated with scrap. The third performance measure is used to estimate material handling time and costs. These performance measures are then used as inputs to the Analytic Hierarchy Process (described by Canada, et al [7]) for the economic justification of the FMS. An example of a job shop system and two alternative FMS is given to illustrate the methodology (Chandra, et al [8]).

The use of decision support systems (DSS) is also being explored as an effective way to economically justify FMS. Monahan, et al [18] explain how a multilevel DSS can be used to evaluate the conversion of batch production processes to automated flexible manufacturing processes. This evaluation requires linking together three levels of analysis in order to ascertain the performance of the total system: (1) the long-term, firm-planning level, (2) the medium-term, factory-operating level, and (3) the automated-work-cell-design level. By linking all three levels within one evaluation system, appropriate cost parameters can be estimated in one level and used in another (Monahan, et al [18]).

### 3.8 Advanced Cost Management System (U.S. Air Force)

A recent project involving the U.S. Air Force has resulted in the development of an advanced cost management system (ACMS) that will assist companies with newly automated factory environments cope with many of the aforementioned cost system problems (Keegan, et al [15]). The ACMS is a strategic, closed-loop DSS that relies on managerial estimates of future costs and monitors actual results against the organizational, departmental, and product plans. It addresses management questions about cost at many organizational levels. The authors remark that many businesses may have already adopted some of the features of

ACMS, or variations upon them. Several of these features are presented below:

- **Prospective Costs.** ACMS directs attention toward prospective future costs and the drivers that impact these costs. It provides current actual information for comparison against the plan and articulates historical information to assist in the development of the future plan.

- **Focus on Part Costs.** ACMS provides information on a part-by-part level for accumulation at the product-reporting level. The part-cost orientation of ACMS provides information concerning value added and value lost in the process, allowing for product cost control at the most detailed level.

- **Process Orientation.** ACMS collects at the process, or cell level, making it possible to pinpoint specific manufacturing steps that require attention, both as they relate to a particular part and to the process overall. Scrap, yield, rework, labor, machine utilization, and so forth will all be visible at the process level.

- **Variance Identification.** ACMS is a process-based system that requires predetermined estimates of actual results. Differences between the predetermined estimates and actual results are reported as variances - planning gaps. These differences, carefully classified by "causing" factors, reveal in detail the reasons for the variances.

- **Management Information Systems.** An organization's data processing costs - operational and financial systems, mainframes, microcomputers, process controllers and networks - are so pervasive in today's environment (perhaps 2% to 4%

of sales) that ACMS distributes them to every department in the company, often based on usage. This approach signals that management information systems is not a free resource, but rather a very expensive part of the manufacturing process (Keegan, et al [15]).

The authors describe eight additional features of ACMS that combine to make it a very powerful and useful system. An illustrated application of ACMS is provided along with several related diagrams, two of which are shown in *Appendix A* of this project.

### 3.9 Cost Accounting System (CAS) Design Principles

As a member of the Boston University Manufacturing Roundtable, Alfred Nanni, Jr. has performed extensive research in the area of manufacturing cost and performance measurement. In one research paper, Nanni [20] has presented a description of several apparently successful "new" cost accounting systems (CAS) operating in "modern" manufacturing environments. Some preliminary interpretations of their common features and the implications they hold for CASs in general have also been offered. From these examples, the author has derived five underlying principles of CAS design, listed below:

1. CASs should conform to the basic precepts traditionally held for them, that is, they should comprise a cause-effect model of the production process in dollar terms.

2. The choice of variables to be employed in that model should be based on an examination of the cause-effect relationships, not an unthinking adoption of the traditional

material-labor-overhead breakdown.

3. CASs should measure costs in relation to the effects the organization wishes to achieve, that is, pursuant to production goals and strategies.

4. CAS models should acknowledge the nature (order) and variables of cause-effect relationships by assigning costs through different overhead pools at different points in the system.

5. CAS models should exploit the hierarchy of the production system's organization by pooling and assigning different groups of costs, segregated by order of effect, at each level (Nanni discusses this in a later reference).

Nanni [20] concludes this paper by explaining that this discussion is merely the first stage in a research program aimed at eventually describing the characteristics and approaches that make a CAS appropriate to a particular situation. All this work does is develop a little clearer view about how to characterize CASs.

In a follow-on research paper, Nanni [19] writes that different organizations, and even different levels within the same organization, are capable of having different performance measurement systems. He has developed a contingency model for performance measurement requirements that may help to identify the points at which performance measurement systems may be dysfunctional, where financial versus nonfinancial measures make sense, and how performance measurement systems should be hierarchically arranged.

### 3.10 Cost Accounting by Goals and Strategies (CAGS)

In yet a later research paper, Nanni, et al [21] have developed a cost accounting system called Cost Accounting by Goals and Strategies (CAGS), that is essentially a modification to traditional systems. The CAGS perspective can be characterized as a matrix view of manufacturing. The columns of the matrix are organizational units, functions or any "entities" for which costs are collected in the firm. These are in essence the avenues of expenditures. The rows are the goals or purposes of the expenditures. Physical activities such as making products (conversion), as well as the more conceptual objectives of quality, process improvement, logistics management, data collection, or organizational learning might be included here.

The CAGS matrix would essentially be manipulated as follows: The manager of each particular department or group would have a total dollar budget equal to the column total. He must determine how much of the budgeted total in each column should be dedicated to each of the row activities. He might begin by determining a percentage allocation for each row. The authors point out that in their illustrated example, the column totals are equivalent to the data used by existing financial reporting systems. The matrix approach simply extends and enhances the traditional cost assignment process. The point of the matrix model is to match costs from spending areas with applications.

The authors extend their application of the CAGS approach by employing a set of heirarchically related matrices. The rows of these sub-matrices are named after the more concrete activities and goals that support the strategies (broad purposes) defined at the "parent" matrix level (while defining its rows). The sub-matrix row names are less abstract because at lower levels in the organization the activities that support the strategies can be stated more specifically. Again, the manager might determine a percentage allocation for each row.

"Dollarized" results can be obtained by multiplying the column total by the percentage of effort assigned to each cell. These matrices can be used for a variety of analyses. The "parent" matrix provides an expected expenditure for each strategic objective in the firm. These matrices, and various adaptations thereof, can be used for many applications, several of which are highlighted by the authors. *Appendix B* of this project demonstrates a partial numerical application of CAGS at work.

The strengths of CAGS are many. A CAGS matrix view encourages examination of how resources are deployed and how they support strategies and goals. CAGS is simple - both in concept and in implementation. The model builds off of an existing database and existing processes. Almost any spreadsheet package will provide the desired computational framework. As experience is gained, one should expect to refine the definitions of columns and rows (Nanni, et al [21]).

Another member of the Manufacturing Roundtable, Duncan C. McDougall, contributes some constructive ideas on how to structure a more effective system for measuring manufacturing performance. He basically concurs with most of the researchers cited herein by stating that, in general, manufacturing should encourage the broadening of what is now called "cost accounting" to include performance measures other than dollars. The result could be a better understanding throughout the firm of the competitive impact of manufacturing, and a view of the function as more than a cost generator (McDougall [16]).

**3.11 Some Useful Guidlines**

McDougall [16] also provides some guidelines (listed below) that may assist a firm in determining if it has an effective performance measurement system.

A. Does the system promote learning?

B Does the system focus on competitive variables (those customers see)?

C. Does the system improve the health of the whole business by increasing throughput, decreasing inventory and decreasing operating expense?

D. Does the system demand improvement on only the strategically chosen variable, while the others are not allowed to backslide?

If a company can answer "yes" to each of these questions, McDougall believes that it has an effective performance measurement system.

**3.12 A Framework for Developing New Performance Measures**

A third member of the Manufacturing Roundtable, Thomas E. Vollmann, presents a three phase framework aimed toward the actual development of appropriate performance measures. The first phase is entitled "Tinkering with Cost Systems."

Many companies modify existing systems to redress inadequacies in costing systems, typically by changing overhead allocations. Unfortunately, writes Vollmann, these efforts are largely misguided since they provide no new values to customers or no new efficiencies in manufacturing. Systems that have been developed to report the financial stewardship position of the firm to outside interests are not appropriate for internal decision making and control. General Dorio of the Harvard Business School summed it up well in his advice to students: Spend your time making it or selling it - not counting it (Vollmann [33]).

The second phase of Vollmann's three phase framework for changing manufacturing measurement is called "Cutting the Gordian Knot." This phase involves a conscious decision to no longer be constrained by cost accounting in the development of manufacturing performance measures. Financial reporting will not be linked to internal decision making, feedback, and control. Several company examples are described.

The last phase, "Embracing Change," links measurement explicitly with strategy. Manufacturing performance should be contingent upon manufacturing goals. As certain goals are achieved, new ones should be developed. As the marketplace changes, new responses are required. All of this means that performance measures can and should be changed. The companies that position themselves to make these changes faster, with less conflict, will be winners (Vollmann [33]).

### 3.13 CAM-I's Cost Management System (CMS)

Another organization that has been significantly involved in cost management research is Computer Aided Manufacturing-International, Inc. (CAM-I), consisting of individuals from public accounting, industry, government agencies and academia. Formed in 1986, the goal of CAM-I was to provide an international forum where cost management experts could share ideas and experiences and consolidate their knowledge about practices that have proven successful in an automated environment. Berliner, et al [5], in a 250-page text, provide extensive discussion of the on-going research at CAM-I. The early chapters present the objectives, principles and goals of a well-structured cost management system (CMS). Later chapters expand on topics introduced in the first three. Included are discussions in the following areas:

- Development, implementation, and use of a cost-benefit tracking system.

- Use of the Multiple-Attribute Decision Model (MADM) to help make cost-effective investment decisions. This method is essentially the same as the Weighted Evaluation Method (WEM) mentioned earlier.

- Use of an expert system for investment justification. This expert system is described later in this paper via a separate reference.

A third group, the National Association of Accountants (NAA), has been involved in related cost accounting research including several joint projects with CAM-I. The research findings of CAM-I, NAA, and the Boston University Manufacturing Roundtable are very similar, and can be summarized as follows: As strategies change for the firm, new performance measures will have to be developed throughout the organization. These goals will serve to change the culture and behavior of people involved in new action programs (Romano [25]).

### 3.14 Improved Pre and Post Adoption Evaluation

While much of the research discussed thus far focuses on the various tools, guidelines, frameworks, decision support systems, etc., that are being developed to more adequately represent and justify new technologies, some researchers believe that managers simply need to pay greater attention to the data already available to them. In Section 2 of this paper, Gold [10] is quoted saying that some of the problems in justifying new technologies can be attributed to misperceptions of managers both in evaluating capabilities before adoption and in appraising results after substantial use. In the same reference, Gold offers some ideas for improving predecision estimates as well as evaluating and improving results after installation.

The author first writes that systematic efforts to analyze the shortcomings of past predesision estimates need to be made. In short, having already paid for past adoption experiences, why not make serious efforts to learn from them? Gold discusses various reasons why managers generally fail to make these efforts.

A second approach to improving preadoption estimates involves probing the experiences of earlier adopters. If domestic adopters are competitors who are unwilling to share such learning, it is often fruitful to explore the possible cooperation of foreign adopters. Still another approach involves reviewing the expected advantages, limitations, and problems of contemplated innovations with specialized consultants as well as competing vendors. Of course, managers can reduce the risk of erroneous estimates by waiting until competitors implement and debug an innovation. But the longer they wait, the lower the remaining competitive benefits to be achieved. The optimal strategy, therefore, seems to combine aggressive exploration of technical frontiers with serious efforts to learn from past errors in evaluating them (Gold [10]).

Finally, regarding problems with post-installation evaluations, Gold [10] writes that greater emphasis needs to be placed on determining the causes of deviations from expected results. In particular, management needs to learn to what extent unexpected shortcomings in the innovation's performance were due to:

- unrecognized equipment characteristics;
- needed engineering modifications;
- unexpected maladjustments in input and work flows; or
- additional changes in labor contributions.

This analysis would make preevaluations more broadly perceptive and would also foster more thorough planning and utilization efforts. In addition, to be more effective, evaluations need to be made repeatedly at six-month intervals for at least the two to three years that the complete absorption of a major innovation takes. Among other resulting benefits, these periodic evaluations would reveal trends in various performance measures, thereby demonstrating which shortcomings are persistent and which are not (Gold [10]). Discussion is also provided regarding which person or group in an organization should have responsibility for performing evaluations.

### 3.15 XVENTURE - An Expert System

Perhaps the most intriguing research idea involves using the emerging technology of expert systems to help justify investments in new technology. **XVENTURE** is a turnkey expert system (developed by W. G. Sullivan and S. R. LeClair) developed to run on an IBM PC. It gives a decision maker the expertise to analyze strategic, nonquantifiable decision attributes that lend themselves well to heuristic analysis. It also preserves otherwise perishable human expertise and reduces the risks of poor human performance. XVENTURE is based on six broad justification issues:

1. Managing today's investment options for future growth.

2. Matching the firm's strategic business plan with its technology plan.

3. Modifying accounting practices to reflect changes in cost patterns due to proposed increases in capital intensity.

4. Accomodating the uncertainties in the business environment and in the technology itself.

5. Considering the benefits of improved manufacturing flexibility, quality, and productivity.

6. Evaluating traditional checks on a proposed project's return characteristics.

These issues are posed to the decision maker in question format. The XVENTURE screen starts with the first question and lists the available responses. After the user selects a response, the program moves to the next question and so on through all six. The responses to the six questions form the basis for a decision by the expert system. The three decisions are: (1) Venture is justifiable-**GO**; (2) Decision is no go for now-**DEFER**; and (3) Reject/Abandon venture-**NO GO**. The responses to the six questions form 648 possible rules of which only 66 lead to the **GO** or **DEFER** recommendation (Sullivan, et al [31]). The article includes detailed discussion on each of the six issues outlined above in addition to their impact on CIM venture justification. Several illustrations that help explain XVENTURE's rule structure are also provided.

### 3.16 Multi-Attribute Decision Analysis (MADA)

It is this author's opinion that multi-attribute decision analysis (MADA) comes closest to being a method capable of adequately representing and justifying a broad range of investment opportunities. Eighty-nine percent of the Fortune 500 executives who responded to a 1986 national survey reported that they experienced great difficulty in quantifying the intangible benefits of various investment options (Bennett, et al [3]). One of the great strengths of MADA is that it does a decent job of quantifying those intangibles, provided that management uses it the correct way.

Canada, et al [7] describe a number of numerical as well as graphical MADA techniques, several of which have been effectively applied to a real-life scenario. Scherbenske [28] investigates the Navy's missile procurement process by utilizing two very popular MADA approaches. The Weighted Evaluation Method (WEM) and the Analytic Heirarchy Process (AHP) are used to demonstrate how defense (in this case) contractors may be chosen not only on quality and cost, but other factors as well, including those considered to be intangible. A case study describing this work in greater detail is provided in the next section. While this effort focuses on selecting a defense contractor, the same procedures described throughout the paper can be applied to a myriad of other multiattribute decision problems, including the justification of a CIM system.

# 4 CASE STUDY

## 4.1 Introduction

Each year the Navy's Cruise Missiles Project (of the Naval Air Systems Command) awards contracts to McDonnell Douglas Astronautics Company (MDAC) and General Dynamics/Convair Division (GD/C) to build Tomahawk Cruise Missiles (See Figure 1). These contractors compete for the award each year by submitting sealed-bid proposals. The Navy awards 70% of the total buy to the contractor with the lowest bid and the remaining 30% to the competition "loser." MDAC and GD/C in turn award contracts in a similar manner to various subcontractors to build the various subcomponents, including the main Guidance System (See Figure 2) component, the Reference Measuring Unit/Computer (RMUC), shown in Figure 3.

Most of the contracting personnel in these organizations claim that other factors in addition to cost are considered when determining contract award winners. This claim is somewhat suspect given the fact that contracts are supposedly awarded to the lowest bidder.

This case study investigates the Navy's missile procurement process by utilizing two very popular multiattribute decision analysis (MADA) approaches. The Weighted Evaluation Method (WEM) and the Analytic Heirarchy Process (AHP), are used to demonstrate how defense (or any other industry) contractors may be chosen based not only on quality and cost, but other factors as well. This work will also indicate whether applying these techniques would have made a difference in fiscal year 1988, a year in which GD/C was the contract "winner." The evaluations contained herein are based on cost data from that year. Point of contact at the Cruise Missiles Project (CMP) was Captain Daniel O'Connor.


U.S. AIR FORCE/GENERAL DYNAMICS
GROUND LAUNCHED
CRUISE MISSILE
WEAPON SYSTEM

Figure 1

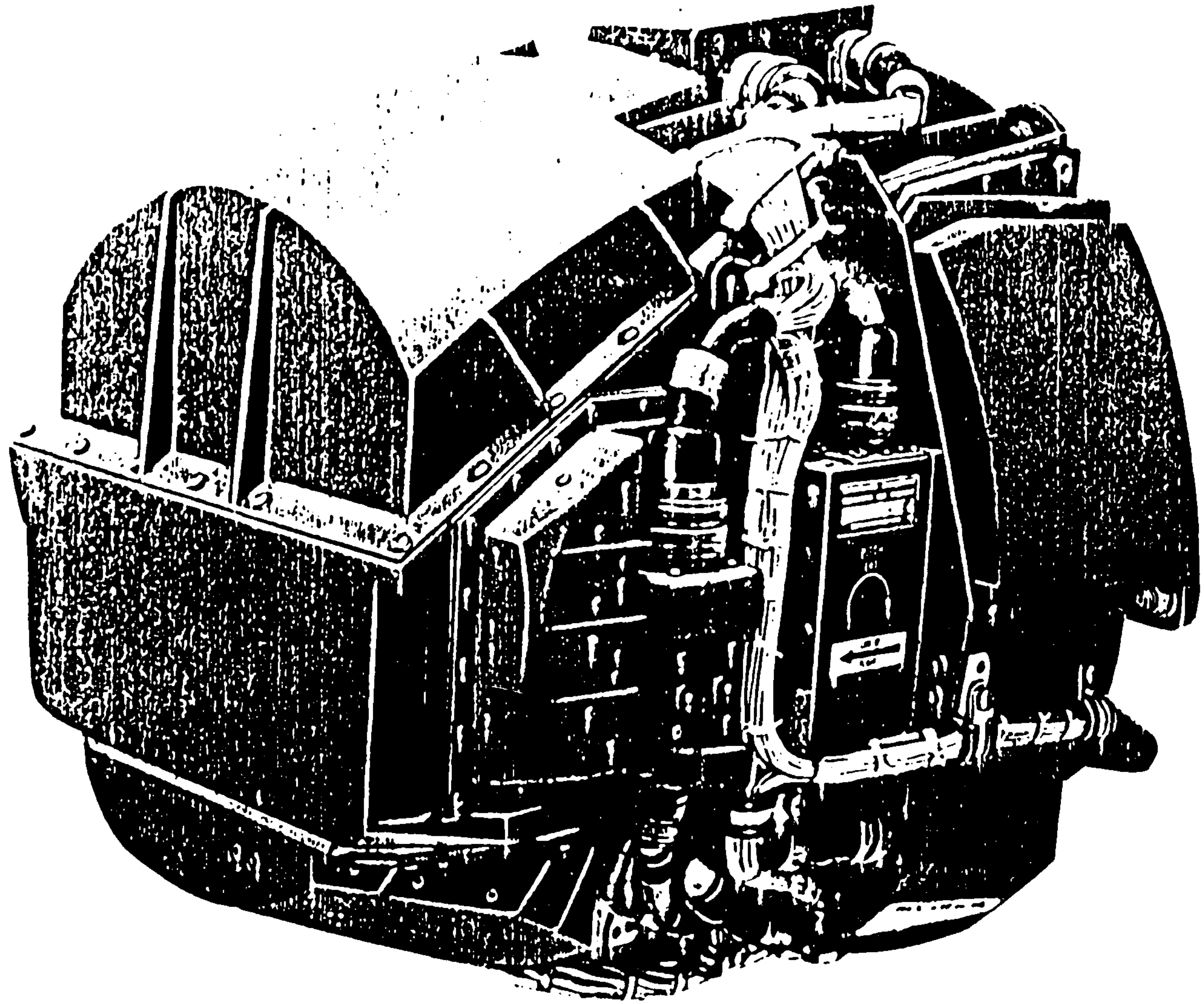


Figure 2. Air, Ground, and Sea Launched Cruise Missile Guidance System

## REFERENCE MEASUREMENT UNIT AND COMPUTER (RMUC)

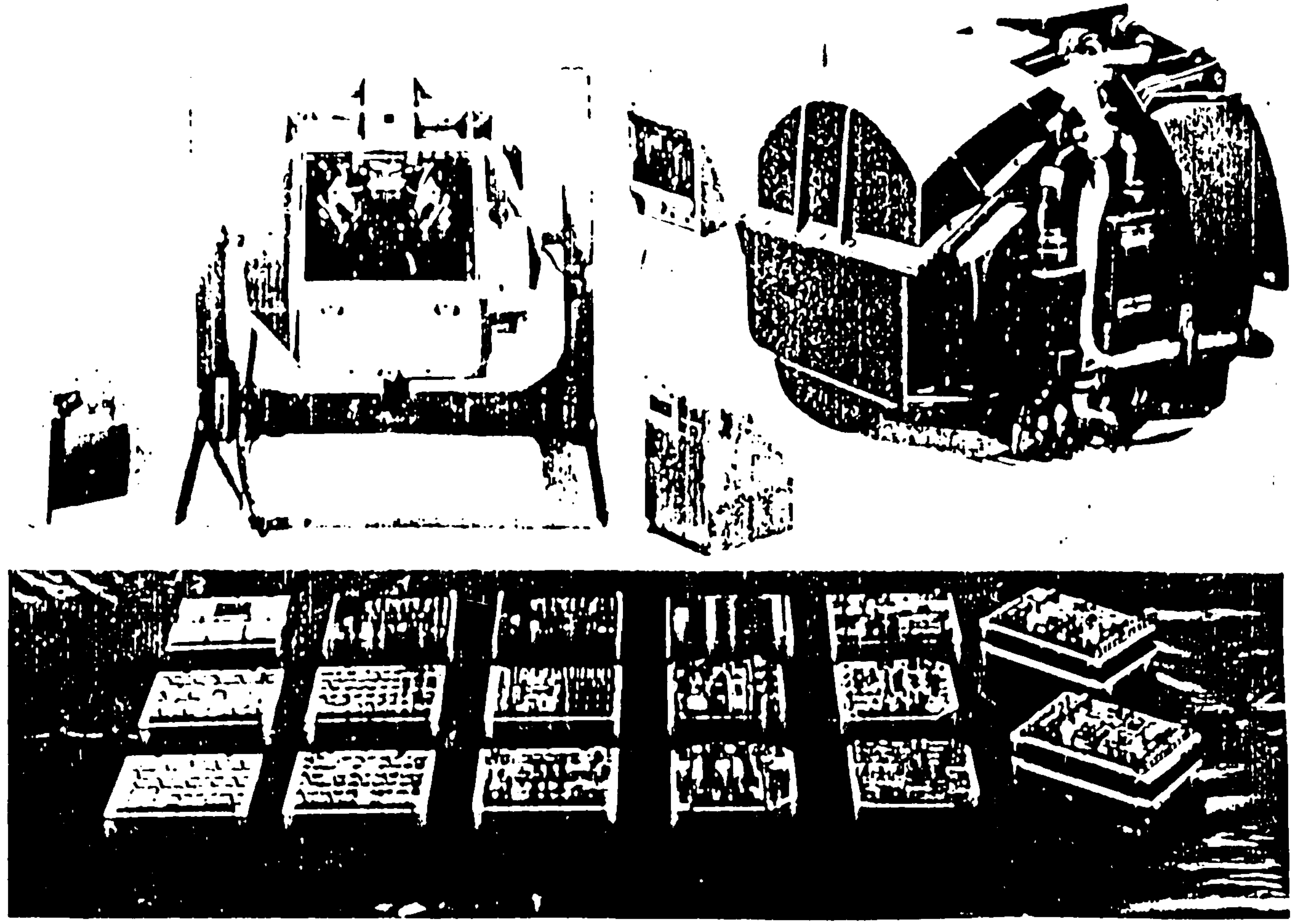


Figure 3

## 4.2 Project Development

After discussing the goals for this project with Captain O'Connor and providing him with some basic background information on the WEM and the AHP, the following steps were taken:

### 4.2.1 Selection of Attributes.

The following five attributes were determined to be most important:

A. **Quality.** This attribute could have been broken down into various subattributes such as availability, reliability and maintainability. However, due to time constraints and limited availability of data, evaluations were based on percentage of failures in the field that required maintenance.

B. **Cost.** Because of the intense competition between the contractors for business (in addition to the effect of the "learning curve"), the unit cost per missile has decreased almost every year. This has resulted in the contract "winner" alternating from MDAC to GD/C and back almost every year. As previously mentioned, this work is based on cost data for FY 1988.

C. **Delivery Schedule Performance.** Not much explanation is required here. This attribute simply involves how well a contractor meets contractual delivery requirements.

D. **Management.** Evaluations involving this attribute were accomplished by answering questions such as:

1. How easy is the contractor to work with?

2. How responsive is the contractor to engineering changes, emergencies, and other unpredictable events?

3. Do they get the job done?

E. **Company Reputation.** Evaluations involving this attribute were accomplished by answering questions such as:

1. Does the contractor have a history of problems with the Government (i.e., falsifying data, collusion, tampering with contracts)?

2. Is there a history of labor problems?

### 4.2.2 Ranking of Attributes.

The method of paired comparisons (Canada, et al [7]) was used to rank order the attributes. It was found that:

| | |
|---|---|
| A > B | B > D |
| A > C | B > E |
| A > D | C > D |
| A > E | C > E |
| B > C | D > E |

Thus, by inspection, the rank order of attributes should remain A > B > C > D > E.

## 4.3 Weighted Evaluation Method.

### 4.3.1 Initial Weight Assignments.

Once attributes were established and ranked in order of decreasing preference, Captain O'Connor assigned initial weights to the attributes (based on the relative importance of each). These are shown in Table 1-1, immediately followed by appropriate checks for consistency.

Table 1-1

MATRIX OF INITIAL WEIGHTING ASSIGNMENTS

| Attribute | Identification | Initial Weighting Assignment |
|---|---|---|
| Quality | A | 100 |
| Cost | B | 80 |
| Schedule Performance | C | 70 |
| Management | D | 40 |
| Company Reputation | E | 20 |

Consistency Check

1. Judgment: $W(A) < W(B) + W(C)$
   Weights: $100 < 80 + 70;\ 100 < 150;\ \therefore$ OK

2. Judgment: $W(B) < W(C) + W(D)$
   Weights: $80 < 70 + 40;\ 80 < 110;\ \therefore$ OK

3. Judgment: $W(C) > W(D) + W(E)$
   Weights: $70 > 30 + 15;\ 70 > 45;\ \therefore$ OK

### 4.3.2 Normalization of Weights.

Once the weights are determined to be satisfactory, they are normalized to sum to 100 points by multiplying each individual weight by

$$\frac{100}{\sum_{i=1}^{\eta} W(Fi)}$$

The results are shown in Table 1-2.

Table 1-2

CALCULATION OF NORMALIZED ATTRIBUTE WEIGHTS.

| Attribute | $\left[\begin{array}{l}\text{Weight}\\ = W(\cdot)\end{array}\right]$ | Normalized Attribute Weight $\left[= \dfrac{W(\cdot)\times 100}{\Sigma\, W(\cdot)} = W_i\right]$ |
|---|---|---|
| A. Quality | 100 | 34 |
| B. Cost | 80 | 27 |
| C. Schedule Performance | 70 | 24 |
| D. Management | 30 | 10 |
| E. Company Reputation | 15 | 5 |
| | $\Sigma\, W(\cdot) = 295$ | $\Sigma = 100$ |

### 4.3.3 Weighted Evaluation of Alternatives

Once weights have been assigned to attributes, the next step is to assign numerical values regarding the degree to which each alternative satisfies each attribute. This was accomplished using an arbitrary scale between 0 and 10. Results are shown numerically in Table 1-3 and graphically in Figure 4.

Once the evaluations have been made, the results are calculated as in Table 1-4 to arrive at weighted evaluations of attributes for each alternative. Thus the summed weighted evaluation is 72.0 for MDAC and 69.4 for GD/C, which indicates that MDAC is the "better" contractor. This corresponds, coincidentally, with the fact that MDAC has the higher evaluation rating for three out of the five attributes. This is not always the case, however, in that frequently an alternative will be determined to be better even though it may have lower evaluation ratings for three or even four out of the five attributes.

Table 1-3

EVALUATION RATING OF HOW WELL EACH CONTRACTOR SATISFIES EACH ATTRIBUTE.

| | Contractor | |
|---|---|---|
| Attribute | MDAC | GD/C |
| A. Quality | 8 | 6 |
| B. Cost | 5 | 7 |
| C. Schedule Performance | 7 | 9 |
| D. Management | 10 | 6 |
| E. Company Reputation | 9 | 5 |

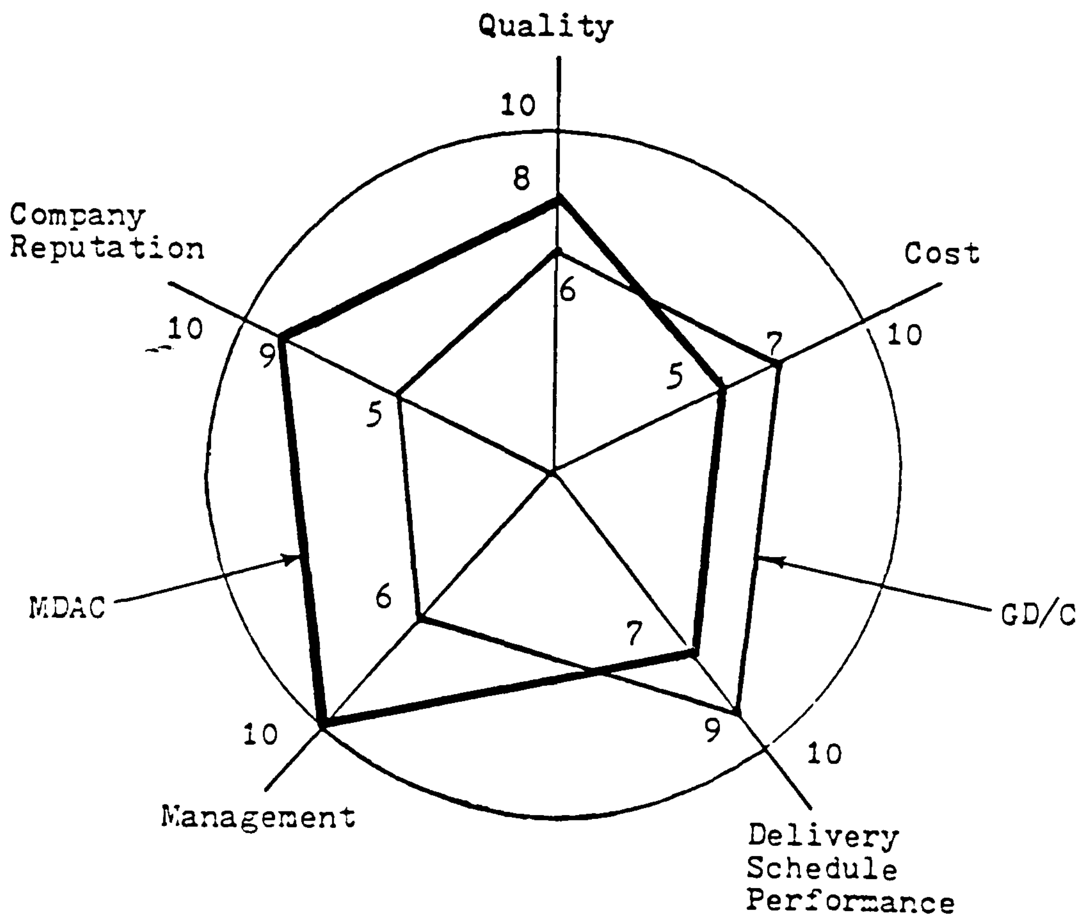



Figure 4. Polar Graph for Two Contractors and Five Attributes.

Table 1-4

CALCULATION OF WEIGHTED EVALUATIONS OF ALTERNATIVES.

| Attribute | Normalized Attribute Weight (From Table 1-3) | MDAC Evaluation Rating | MDAC Weighted Evaluation* | GD/C Evaluation Rating | GD/C Weighted Evaluation* |
|---|---|---|---|---|---|
| Quality | 34 | 8 | 27.2 | 6 | 20.4 |
| Cost | 27 | 5 | 13.5 | 7 | 18.9 |
| Schedule Performance | 24 | 7 | 16.8 | 9 | 21.6 |
| Management | 10 | 10 | 10.0 | 6 | 6.0 |
| Company Reputation | 5 | 9 | 4.5 | 5 | 2.5 |
| | | | $\Sigma = 72.0$ | | $\Sigma = 69.4$ |

*Weighted evaluation = normalized attribute weight x $\frac{\text{evaluation rating}}{10}$

Thus MDAC (with a weighted evaluation of 72.0) is determined to be slightly more desirable than GD/C.

### 4.4 Analytic Hierarchy Process (AHP)

#### 4.4.1 Construction of Hierarchy

Having completed the Weighted Evaluation Method, it was relatively simple to construct the three-level hierarchy (see Figure 5) as required by the Analytic Hierarchy Process (AHP). If subattributes had been included, the hierarchy could have been expanded downward as many levels as required. Note that in Figure 5 the objective is at the top level while the alternatives are at the lowest level with the five attributes in the middle.

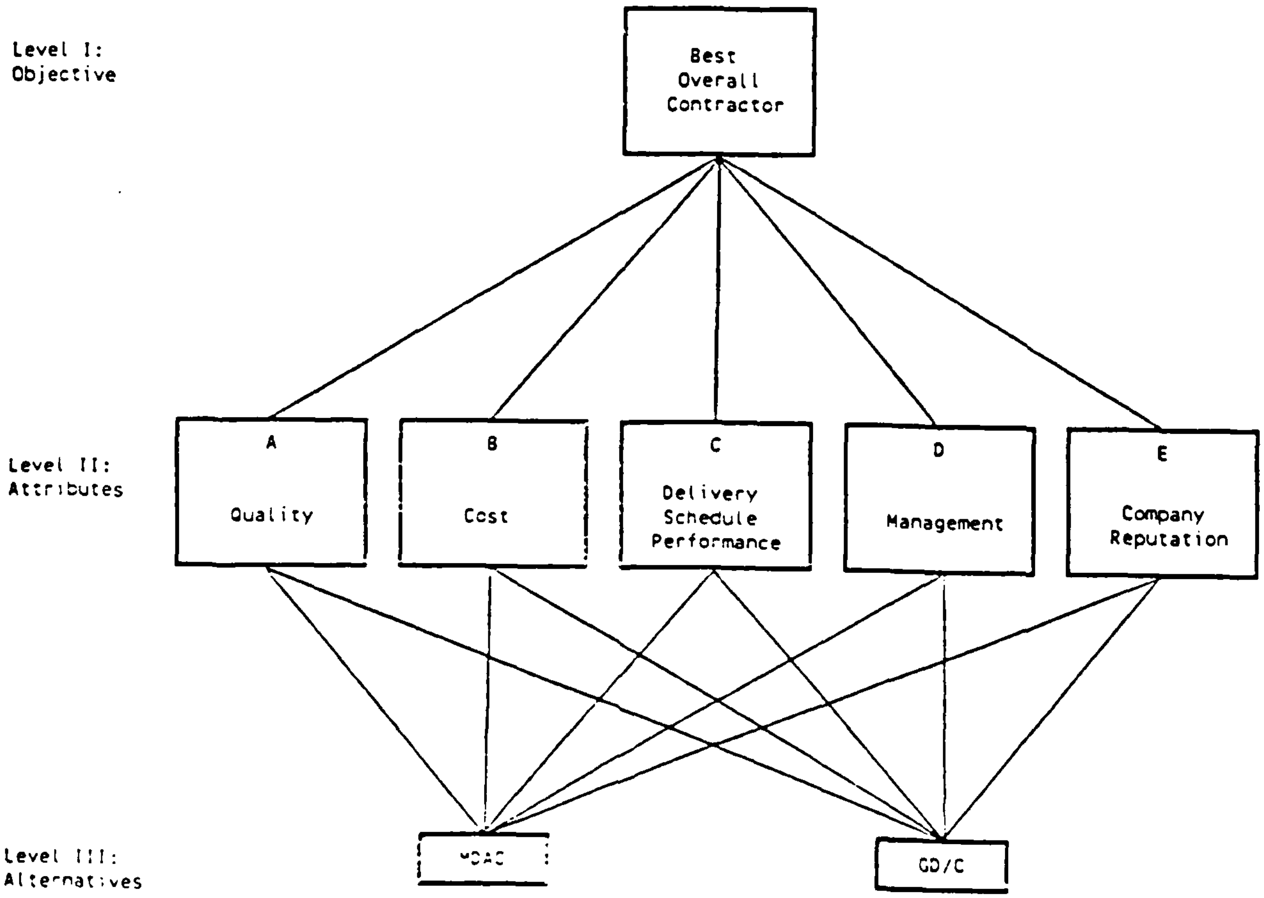



Figure 5. Decision Hierarchy

## 4.4.2 Pairwise Comparison of Attributes

Since the general approach of the AHP as described by Canada, et al [7] is to decompose the problem and to make pairwise comparisons of all elements (attributes, alternatives, etc.) on a given level with respect to the related elements just above, Captain O'Connor was asked to make these kind of comparisons (with the help of Figure 6).

Importance (or preference) of one attribute over another

| With Respect to:-- | | Absolute | | very strong | | strong | | weak | | equal | | weak | | strong | | very strong | | absolute | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Attribute | | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Attribute |
| Quality | A | | | | | | | x | | | | | | | | | | | B. Cost |
| | A | | | | | | | x | | | | | | | | | | | C. Del. Sched. Perf. |
| | A | | | | | | x | | | | | | | | | | | | D. Management |
| | A | | | | | x | | | | | | | | | | | | | E. Comp. Rep. |
| Cost | B | | | | | | x | | | | | | | | | | | | C. Sched. Perf. |
| | B | | | | | x | | | | | | | | | | | | | D. Mgmt. |
| | B | | | | x | | | | | | | | | | | | | | E. Comp. Rep. |
| Del. Sched. Perf. | C | | | | | x | | | | | | | | | | | | | D. Management |
| | | | | x | | | | | | | | | | | | | | | E. Comp. Rep. |
| Comp. Rep. | D | | | | | x | | | | | | | | | | | | | E. Comp. Rep. |

Figure 6. Questionnaire form used to facilitate preference comparisons (numerical results are show in Table 2-1.

This type of questionnaire form is typically used to facilitate preference comparisons. The numerical scale shown across the top of Figure 6 is based on recommendations by Saaty [26]. To express degrees of preference between two elements X and Y, Saaty suggests the following guidelines:

| If x is . . . as (than) y | then the preference number to assign is: |
|---|---|
| equally important/preferred | 1 |
| weakly more important/preferred | 3 |
| strongly more important/preferred | 5 |
| very strongly more important/preferred | 7 |
| absolutely more important/preferred | 9 |

Even numbers (2, 4, 6 and 8) can be used to represent compromises among the preferences above. The data provided is Figure -6 led to the development of a matrix of paired comparisons for attributes, Table 2-1.

Table 2-1

MATRIX OF PAIRED COMPARISONS (INCLUDING DECIMAL EQUIVALENTS) FOR ATTRIBUTES.

| | | | | | | Decimal Equivalents | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | A | B | C | D | E |
| A. Quality | 1 | 3 | 3 | 4 | 5 | 1 | 3 | 3 | 4 | 5 |
| B. Cost | 1/3 | 1 | 4 | 5 | 6 | .33 | 1 | 4 | 5 | 6 |
| C. Schedule Performance | 1/3 | 1/4 | 1 | 5 | 7 | .33 | .25 | 1 | 5 | 7 |
| D. Management | 1/4 | 1/5 | 1/5 | 1 | 5 | .25 | .20 | .20 | 1 | 5 |
| E. Company Reputation | 1/5 | 1/6 | 1/7 | 1/5 | 1 | .20 | .17 | .14 | .20 | 1 |
| | | | | | | $\Sigma$ = 2.11 | 4.62 | 8.34 | 15.20 | 24.00 |

### 4.4.3 Priority Weights for Attributes

The next step involves the computation of a vector of priorities or weighting of elements in the matrix. This consisted of dividing the elements of each column by the sum of that column (i.e., normalize the column) and then adding the elements in each resulting row and dividing this sum by the number of elements in the row. The results are shown in Table 2-2.

Table 2-2

NORMALIZED MATRIX OF PAIRED COMPARISONS AND CALCULATION OF PRIORITY WEIGHTS (APPROXIMATE ATTRIBUTE WEIGHTS).

| | A | B | C | D | E | Row $\Sigma$ | Average $= \Sigma/5$ |
|---|---|---|---|---|---|---|---|
| A | 0.474 | 0.649 | 0.360 | 0.263 | 0.208 | 1.954 | 0.391 |
| B | 0.156 | 0.217 | 0.479 | 0.329 | 0.250 | 1.431 | 0.286 |
| C | 0.156 | 0.054 | 0.120 | 0.329 | 0.292 | 0.951 | 0.190 |
| D | 0.119 | 0.043 | 0.024 | 0.066 | 0.208 | 0.46 | 0.092 |
| E | 0.095 | 0.037 | 0.017 | 0.013 | 0.042 | 0.204 | 0.041 |
| | $\Sigma =$ 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | | 1.000 |

Thus, the attributes have the following approximate priority weights:

| | | |
|---|---|---|
| A. | Quality | 0.391 |
| B. | Cost | 0.286 |
| C. | Schedule Performance | 0.190 |
| D. | Management | 0.092 |
| E. | Company Reputation | 0.041 |

### 4.4.4 Consistency Ratio

Canada, et al [7] explain the steps involved in calculating the consistency ratio (C.R.), which is an approximate mathematical indicator, or guide, of the consistency of pairwise comparisons. The authors write that this C.R. is a function of what is called the "maximum eigenvalue" and size of the matrix (called a "consistency index") which is then compared against similar values if the pairwise comparisons had been merely random (called a "random index"). For this case study, the C.R. can be approximated as follows:

$$\underset{[A]}{\begin{bmatrix} 1 & 3 & 3 & 4 & 5 \\ .33 & 1 & 4 & 5 & 6 \\ .33 & .25 & 1 & 5 & 7 \\ .25 & .20 & .20 & 1 & 5 \\ .20 & .17 & .14 & .20 & 1 \end{bmatrix}} \times \underset{[B]}{\begin{bmatrix} 0.391 \\ 0.286 \\ 0.190 \\ 0.092 \\ 0.041 \end{bmatrix}} = \underset{[C]}{\begin{bmatrix} 2.392 \\ 1.881 \\ 1.138 \\ 0.490 \\ 0.213 \end{bmatrix}}$$

$$[D] = \frac{[C]}{[B]} = \begin{bmatrix} \frac{2.392}{0.391} & \frac{1.881}{0.286} & \frac{1.138}{0.190} & \frac{0.490}{0.092} & \frac{0.213}{0.041} \end{bmatrix}$$

$$= [6.12 \quad 6.57 \quad 5.99 \quad 5.33 \quad 5.19]$$

$$\lambda\, max = \frac{6.12 + 6.57 + 5.909 + 5.33 + 5.19}{5}$$

$$CI = \frac{\lambda\, max - 5}{5-1} = \frac{5.84 - 5}{5-1} = 0.21$$

$$C.R. = \frac{CI}{RI} = \frac{0.21}{1.12} = 0.18$$

The calculated C.R. of 0.18 exceeds the 0.10 empirical upper limit suggested by Saaty [26], which indicates either excessive intransitivities or inconsistencies in stated degrees of preferences. Normally, in a case such as this, the decision maker would attempt to reduce the C.R. by reestimating preferences. However, it is believed that a good, honest attempt was made at making these pairwise comparisons and that further attempts to reevaluate attributes would not necessarily improve the results of this case study.

### 4.4.5 Pairwise Comparison of Alternatives

The next step involves making pairwise comparisons of each of the contractors with respect to each of the attributes to which they relate in the next higher level in Figure 5. This data (using the same guidelines as when comparing attributes) is compiled in Table 2-3.

### 4.4.6 Priority Weights for Alternatives

The next step involves computation of a vector of priorities or weights (in the same manner as previously demonstrated for attributes). The results are shown in Table 2-4.

Table 2-3

PAIRED COMPARISONS (INCLUDING DECIMAL EQUIVALENTS) FOR ALTERNATIVES WITH RESPECT TO EACH ATTRIBUTE.

| Quality | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 4 |
| GD/C | 1/4 | 1 |

| Quality | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 4 |
| GD/C | 0.25 | 1 |
| | Σ = 1.25 | 5 |

| Cost | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 1/3 |
| GD/C | 3 | 1 |

| Cost | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 0.33 |
| GD/C | 3 | 1 |
| | Σ = 4 | 1.33 |

| Schedule Performance | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 1/2 |
| GD/C | 2 | 1 |

| Schedule Performance | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 0.50 |
| GD/C | 2 | 1 |
| | Σ = 3 | 1.5 |

| Management | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 5 |
| GD/C | 1/5 | 1 |

| Management | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 5 |
| GD/C | 0.20 | 1 |
| | Σ = 1.20 | 6 |

| Company Reputation | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 6 |
| GD/C | 1/6 | 1 |

| Company Reputation | MDAC | GD/C |
|---|---|---|
| MDAC | 1 | 6 |
| GD/C | 0.7 | 1 |
| | Σ = 1.17 | 7 |

Table 2-4

NORMALIZED MATRICES OF PAIRED COMPARISONS AND CALCULATION OF PRIORITY WEIGHTS FOR ALTERNATIVES WITH RESPECT TO EACH ATTRIBUTE.

| Quality | MDAC | GD/C | Row Σ | Average = Σ/2 |
|---|---|---|---|---|
| MDAC | 0.80 | 0.80 | 1.60 | 0.80 |
| GD/C | 0.20 | 0.20 | 0.40 | 0.40 |
| | Σ = 1.00 | 1.00 | | 1.00 |

| Cost | MDAC | GD/C | Row Σ | Average = Σ/2 |
|---|---|---|---|---|
| MDAC | 0.25 | 0.25 | 0.50 | 0.25 |
| GD/C | 0.75 | 0.75 | 1.50 | 0.75 |
| | Σ = 1.00 | 1.00 | | 1.00 |

| Schedule | MDAC | GD/C | Row Σ | Average = Σ/2 |
|---|---|---|---|---|
| MDAC | 0.33 | 0.33 | 0.66 | 0.33 |
| GD/C | 0.67 | 0.67 | 1.34 | 0.67 |
| | Σ = 1.00 | 1.00 | | 1.00 |

| Management | MDAC | GD/C | Row Σ | Average = Σ/2 |
|---|---|---|---|---|
| MDAC | 0.83 | 0.83 | 1.66 | 0.83 |
| GD/C | 0.17 | 0.17 | 0.34 | 0.17 |
| | Σ = 1.00 | 1.00 | | 1.00 |

| Company Reputation | MDAC | GD/C | Row Σ | Average = Σ/2 |
|---|---|---|---|---|
| MDAC | 0.86 | 0.86 | 1.72 | 0.86 |
| GD/C | 0.14 | 0.14 | 0.28 | 0.14 |
| | Σ = 1.00 | 1.00 | | 1.00 |

Table 2-5 summarizes all priority weights, in a form which is convenient for calculation of the final result, the vector (priority weights) of alternatives. The weighted evaluation for each alternative/contractor is obtained by multiplying the matrix of evaluation ratings by the vector of attribute weights and summing over all attributes. Thus, for MDAC,

$$0.391(0.80) + (0.286)(0.25) + (0.190)(0.33) + (0.092)(0.83) + (0.041)(0.86) = 0.559$$

which is shown in the right-hand column of Table 2-5. GD/C's priority weight is calculated the same way.

Table 2-5

SUMMARY OF PRIORITY WEIGHTS (ATTRIBUTE WEIGHTS), EVALUATION RATINGS AND WEIGHTED EVALUATIONS

| | Attribute | | | | | Alternative Weighted Evaluation = Σ Attribute Weight X Evaluation Rating |
|---|---|---|---|---|---|---|
| | A Quality | B Cost | C Delivery Schedule Performance | D Management | E Company Reputation | |
| Attribute Weights | 0.391 | 0.286 | 0.190 | 0.092 | 0.041 | |
| Alternative Evaluation Rating: | | | | | | |
| MDAC | 0.80 | 0.25 | 0.33 | 0.83 | 0.86 | 0.559 |
| GD/C | 0.20 | 0.75 | 0.67 | 0.17 | 0.14 | 0.441 |
| | | | | | | Σ = 1.000 |

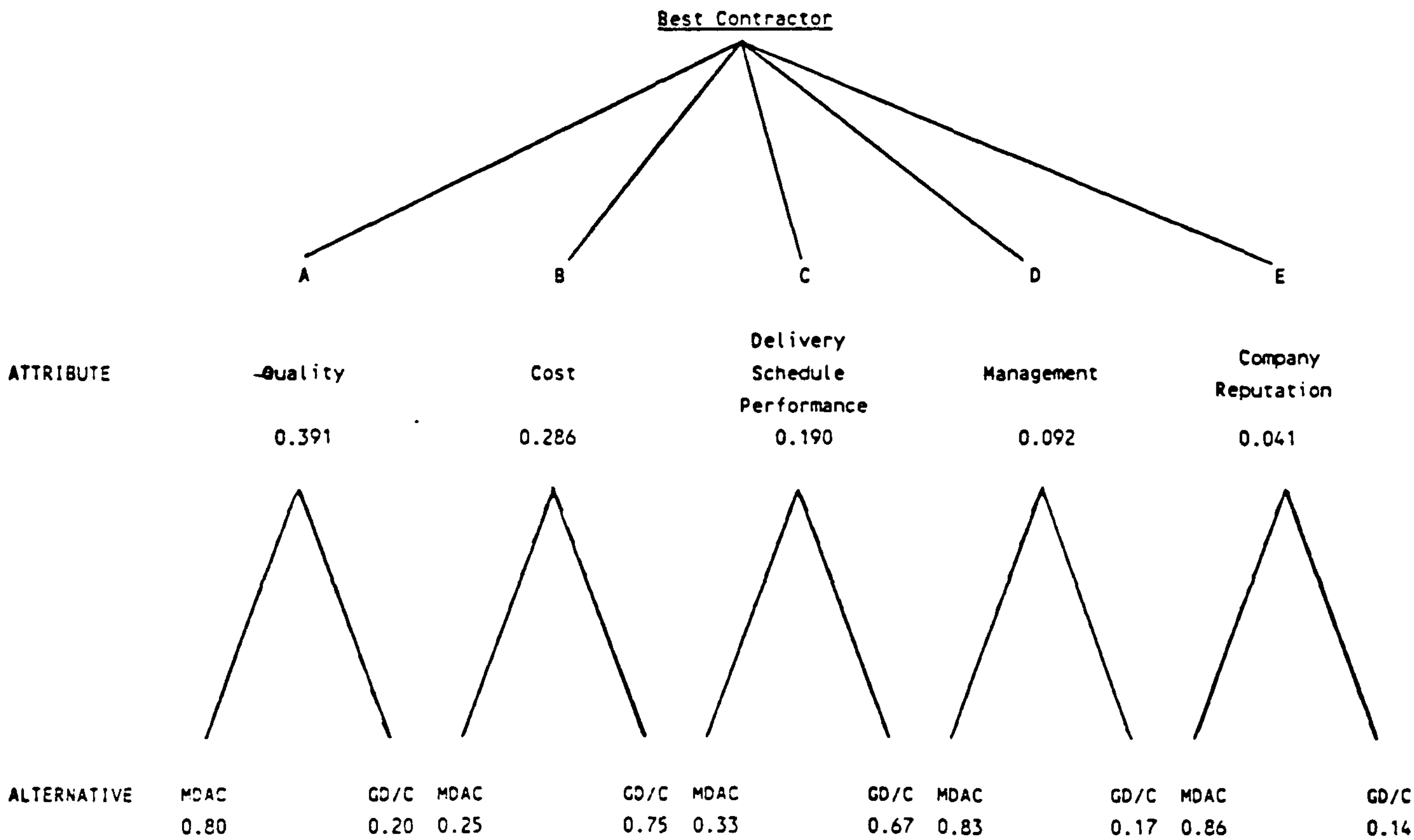
Thus MDAC (with a weighted evaluation of 0.559) is determined to be more desirable than GD/C.

Thus, MDAC is indicated to be more desirable than GD/C (priority weight of 0.441).

Another way to show the structure of this problem and the results of all priority weights is given in Figure 7. Using the results as shown in Figure 7, the priority weight for either alternative can be calculated by summing the products of weights for all branches including that alternative. Thus, for GD/C, the weighted evaluation is

$$0.20(0.391) + 0.75(0.286) + 0.67(0.190) + 0.17(0.092) + 0.14(0.041) = 0.441$$

which is shown in the right-hand column of Table 2-5.




| Results: | Alternative | Priority Weight |
|---|---|---|
| | MDAC | 0.559 |
| | GD/C | 0.441 |

Figure 7. Decision Hierarchy and Priority Weight Results.

## 4.5 Case Study Results

The results of this project indicate that in 1988, the Navy perhaps could have improved upon their decision making process in selecting a contractor. Both of the techniques employed herein show that MDAC, and not GD/C, was the "more desirable" contractor in 1988. Of course, one could argue that since each of the calculated priority weights is based on one person's appraisals and pairwise comparisons, that the results may be inaccurate or unfairly biased. The simple solution to this problem would be to have a group of qualified people determine attributes, make comparisons, assign weights, etc., in a fashion resembling the nominal group technique. In other words, the subjective judgments can be as strong or as weak as desired by increasing or decreasing the size of the group making the appraisals.

It is believed that both the WEM and the AHP should make the decision maker more confident. Canada, et al [7] state that commonly claimed benefits of the AHP are that:

1. It is simple and easy to understand.

2. It necessitates the construction of a hierarchy of attributes, subattributes, alternatives, and so on, which facilitates communication of the problem and recommended solution.

3. It provides a unique means of quantifying judgmental consistency.

The authors also point out that the AHP provides remarkable versatility and power in structuring and analyzing complex multiattribute decision problems.

Regardless of whether one agrees or disagrees with the results contained herein, two good methodologies for helping to analyze and resolve multiattribute decision problems have been demonstrated. While this effort focused on selecting a defense contractor, the same procedures described throughout the study can be applied to a myriad of other multiattribute decision problems, including the justification of advanced manufacturing technology.

## 5 CONCLUSION

Many research dollars are being spent each year as companies, universities and governments worldwide attempt to find better cost accounting/performance measuring systems. The CMS project (discussed earlier) being conducted by CAM-I is probably the largest ongoing research effort with each sponsor (of the CMS project) paying $15,000 per year, on top of CAM-I's annual membership fee of $12,000. Sponsors include Boeing, General Dynamics, General Electric, Johnson Controls, Lockheed, Xerox, the U.S. Air Force and Navy, and six of the Big Eight accounting firms. Will the CMS project and other related projects stimulate substantial change? Some critics say no. "A lot of people are interested in the cost-management area, but it appears as if the search has not revealed the answer," says William Ferrara, professor of accounting at Pennsylvania State University (Nuccio [23]).

Nuccio [23] adds that, "on the other hand, the clamor for updated cost accounting is intensifying. Outmoded methods are considered one of the main barriers to advanced automation. Thus, the impetus to change is growing stronger, especially as companies feel the tightening squeeze of foreign competition."

Manufacturing companies worldwide are pouring vast sums of money into automating their operations. Boston-based Harbor Research Inc. estimates CIM investments will nearly double to $91 billion in 1992 from 1988's $52 billion (Schatz [27]). But before those investments produce the kinds of returns manufacturing executives are banking on, companies have to thoroughly examine their investment options and make sure that they are optimally allocating those billions of dollars. To do this, they must have cost accounting/performance measuring systems that sufficiently represent and justify these kinds of investments.

It is a foregone conclusion that the potential cost savings to companies that correctly implement CIM are significant. For example, contractors under the Defense Department's Industrial Modernization Incentives Program (IMIP) are encouraged to develop high-risk manufacturing technologies at their own expense (under the appropriate government contract), but IMIP returns a percentage of any realized cost savings to the contractor. Industry-wide, IMIP savings are expected to total $6.3 billion through the 1990s, according to government estimates (Scott [29]). These savings could be even greater if more accurate cost accounting/performance measuring systems were available to the government and industry.

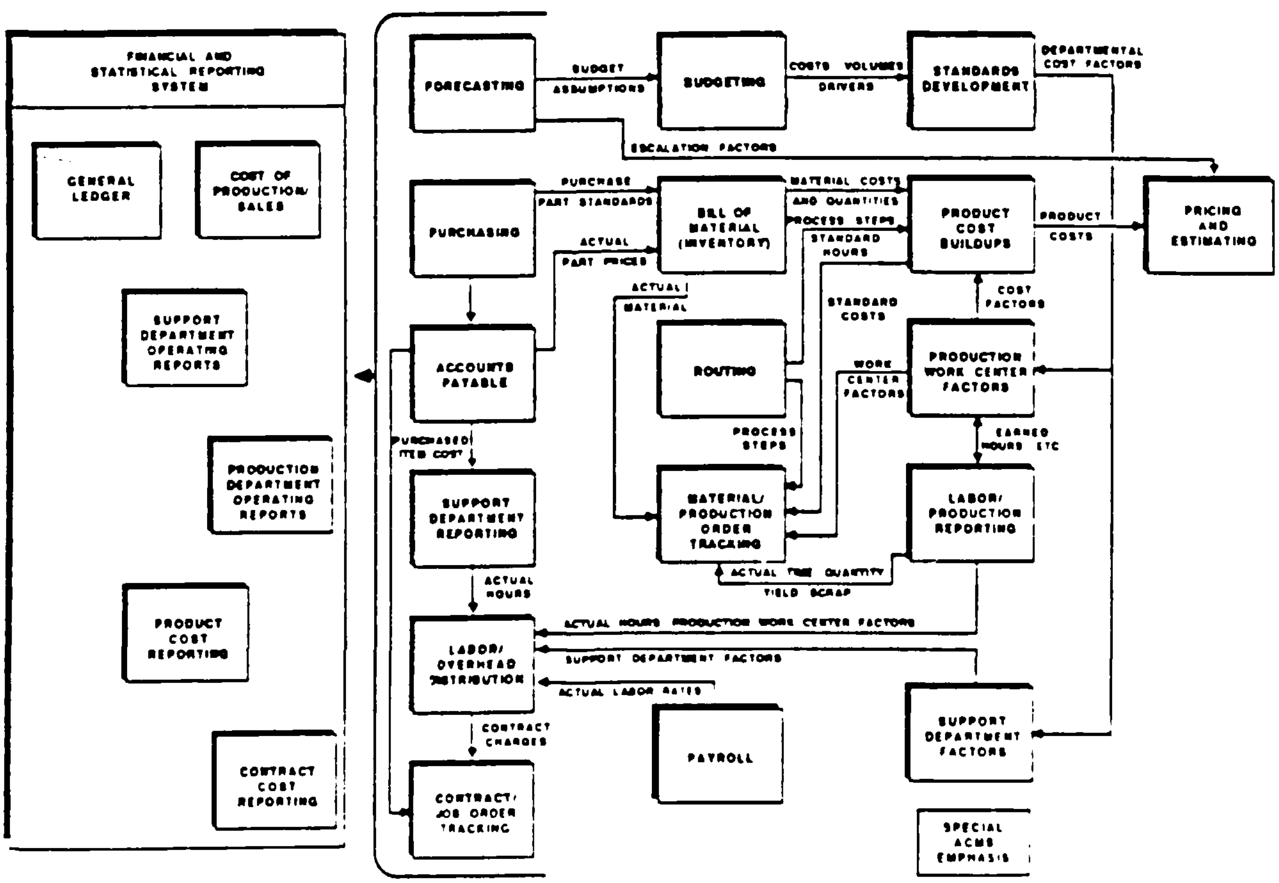
This project presented the opportunity to explain in some detail the wide array of current research efforts geared toward developing new and improved cost accounting/performance measuring systems. Some of the researchers cited herein have tinkered with traditional cost accounting methods. Some have attempted to develop entirely new techniques. Others have developed guidelines and frameworks to help a company decide if it has a good cost accounting system, and if not, how to develop a new system. Several of the authors have made an attempt at integrating the various methodologies currently available. Still others have developed complex decision support and expert systems to help make CIM investment decisions. So where does all this information leave us? As the world continues to reach new heights in automation technology, the accounting and performance measuring systems used to gauge and justify these innovations will continually have to be updated. In short, it is apparent that there is still a vast amount of work to be done in the area of developing new and improved cost accounting/performance measuring systems.

## APPENDIX A

The following figures and associated text are taken directly from Keegan, et al [15] in an attempt to describe in greater detail the Air Force's Advanced Cost Management System (ACMS).

The ACMS described in Section 3.8 of this project has been designed to deal with the cost management issues of a large company. It is comprehensive and integrated. It affects, or is affected by virtually every aspect of the organization. Figure 1 presents a partial description of the subsystems required for an advanced cost management system.

**FIGURE 1 / ADVANCED COST MANAGEMENT SYSTEM PROCESS, SUBSYSTEM, DATA INTERRELATIONSHIPS**



Despite the system's formidable appearance when described in depth, an advanced cost management system is - or can be - relatively straight-forward in operation. Many of the subsystems that support the ACMS exist within most companies.

Part of implementation planning entails assessing how well a company's current systems support the ACMS's objectives. Requirements are documented, allowing the company to evaluate existing systems and determine the changes required to migrate to an advanced cost management system environment. In certain cases, existing systems have to be modified. In other cases they will have to be augmented, and in a few cases, existing systems will have to be scrapped.

Figure 2 presents a road map of the process required to plan the installation of the ACMS.

**FIGURE 2 / ADVANCED COST MANAGEMENT SYSTEM IMPLEMENTATION PLANNING PHASES**

| PHASE I | PHASE II | PHASE III | PHASE IV |
|---|---|---|---|
| APPLY ACMS CONCEPTS TO THE COMPANY | ASSESS CURRENT SYSTEMS CAPABILITIES TO SUPPORT ACMS | TAILOR ACMS DESIGN TO MEET SPECIFIC COMPANY NEEDS | DEVELOP DETAILED IMPLEMENTATION PLAN |
| Activities:<br>■ Present ACMS concepts<br>■ Identify future business changes which will impact cost management<br>■ Determine preliminary advantages and disadvantages to the business of installing ACMS | Activities:<br>■ Interview department managers to determine impact of ACMS on departmental operations<br>■ Identify future systems requirements<br>■ Evaluate current in-house systems status | Activities:<br>■ Determine company subsystem structure required to meet ACMS objectives<br>■ Specifically define functions and features of ACMS subsystems<br>■ Develop ACMS general design<br>■ Identify and resolve major design issues<br>■ Identify potential alternatives | Activities:<br>■ Evaluate implementation barriers<br>■ Assess departmental level procedure requirements<br>■ Design detailed education/training program<br>■ Design system integration requirements<br>■ Determine implementation sequence and strategy<br>■ Identify hardware/software requirements<br>■ Develop detailed implementation plan |
| ■ CHECKPOINT: Ensure understanding of ACMS concepts in view of business objectives | ■ CHECKPOINT: Determine implementation feasibility | ■ CHECKPOINT: Ensure consistency of general design to company objectives | ■ CHECKPOINT: Approve implementation plan |

Without such a road map, it is entirely possible that an organization will spend a great deal of time implementing only a small portion of a comprehensive cost management system. The proper architectural plan may allow management to achieve multifaceted cost management objectives with only a small incremental investment.

## APPENDIX B

The following figures and associated text are adapted directly from Nanni, et al [21] in an attempt to demonstrate in greater detail how Cost Accounting by Goals and Strategies (CAGS) can be applied to an actual manufacturing scenario.

Figure 1 is a partially filled-in CAGS matrix view of the manufacturing budget for XYZ Company. The columns (spending units) include the purchasing department, factory work centers 1 and 2, the computer systems group, engineering, and maintenance. The rows (spending purposes) include conversion, logistics, specification conformance, activity monitoring, conversion improvement, and quality improvement.

**FIGURE 1 / XYZ CORPORATION CAGS MANUFACTURING BUDGET**

| | Purchasing | Work center 1 | Work center 2 | Computer Systems | Engineering | Maintenance | Total |
|---|---|---|---|---|---|---|---|
| Conversion | | 9,810 | | | | | 26,730 |
| Logistics | | 2,370 | | | | | |
| Conformance | | 1,775 | | | | | |
| Activity Monitoring | | 528 | | | | | |
| Conversion Improvement | | 267 | | | | | |
| Logistics Improvement | | 480 | | | | | |
| Quality Improvement | | 720 | | | | | |
| Total | | 15,950 | | | | | |

Note that the first four items on this list relate to current production efforts whose benefits will appear immediately. By contrast, the last three items relate to activities whose benefits can accrue to the firm for many years into the future. Thus, such an explicit partitioning of costs within a department allows a focus on both current and future benefits to today's cost-incurring activities.

One way (there are others) to apply the CAGS approach (build the budget, in this case) is to employ a set of hierarchically related matrices. This is illustrated in Fugures 2,4, and 4. These figures depict the budget matrices that support the master budget data in Figure 1.

Back in Figure 1, the rows were determined by the strategies (broad purposes) pursued by the firm. In contrast, Figure -2 and 3 name the rows after the more concrete activities and goals that support these strategies. The row names are less abstract because at lower levels in the organization the activities that support the strategies can be stated more specifically. The columns in Figures 2 and 3

**FIGURE 2 / CAGS BUDGET "TRAIL" FOR WORK CENTER 1**
**PERCENTAGE ALLOCATION MATRIX**

| | Direct Labor | Indirect Labor | Machine Cost | Power | Engineering | Maintenance |
|---|---|---|---|---|---|---|
| Assembly | .600 | .100 | .800 | .700 | .000 | .700 |
| Movement | .200 | 200 | .100 | .160 | .000 | 100 |
| Rework/Inspection | .100 | 200 | .100 | 095 | .300 | .000 |
| Data Collection | .050 | .100 | 000 | .025 | .100 | .000 |
| Improvement Teams | .050 | 000 | 000 | 000 | .000 | 100 |
| New Schedule | .000 | 200 | 000 | .000 | .100 | 050 |
| Sensors | .000 | 200 | 000 | .020 | 500 | 050 |
| Total $ | $3,750 | 2,000 | 5,000 | 4 000 | 400 | 800 |

## FIGURE 3 / CAGS BUDGET "TRAIL" FOR WORK CENTER 1 "DOLLARIZED" MATRIX

| | Direct Labor | Indirect Labor | Machine Cost | Power | Engineering | Maintenance | Total |
|---|---|---|---|---|---|---|---|
| Assembly | 2,250 | 200 | 4,000 | 2,800 | 0 | 560 | 9,810 |
| Movement | 750 | 400 | 500 | 640 | 0 | 80 | 2,370 |
| Rework/Inspection | 375 | 400 | 500 | 380 | 120 | 0 | 1,775 |
| Data Collection | 188 | 200 | 0 | 100 | 40 | 0 | 528 |
| Improvement Teams | 187 | 0 | 0 | 0 | 0 | 80 | 267 |
| New Schedule | 0 | 400 | 0 | 0 | 40 | 40 | 480 |
| Sensors | 0 | 400 | 0 | 80 | 200 | 40 | 720 |
| Total $ | $3,750 | 2,000 | 5,000 | 4,000 | 400 | 800 | 15,950 |

## FIGURE 4 / CAGS BUDGET "TRAIL" FOR WORK CENTER 1 PERCENTAGE SUMMARY IN FACTORY BUDGET

| | Purchasing | Work center 1 | Work center 2 | Computer Systems | Engineering | Maintenance | Total |
|---|---|---|---|---|---|---|---|
| Conversion | | .615 | | | | | |
| Logistics | | .149 | | | | | |
| Conformance | | .111 | | | | | |
| Activity Monitoring | | .033 | | | | | |
| Conversion Improvement | | .017 | | | | | |
| Logistics Improvement | | .030 | | | | | |
| Quality Improvement | | .045 | | | | | |
| Total | | 15,950 | | | | | |

indicate the various subcategories of expenditure relevant to Work Center 1: direct labor, indirect labor, machinery, power, engineering, and maintenance.

A major part of the activity in Work Center 1 is devoted simply to assembling the product. Figure 1 identifies quality conformance as a strategic goal. Figure 2 shows that Work Center 1 will pursue quality of current production through inspection and rework within the department. Furthermore, Work Center 1 has a specific quality improvement project, installation of machine feedback control sensors, planned for this period. Allocations to these two rows will reflect how department resources will be deployed in order to achieve these results. That is, the entries show whose job it is and how much will be spent in pursuit of this goal in each entity. Actual results (number of quality rejects, percent of project completion) will demonstrate whether these plans were effective or not. The efficiency of the specific activity during the period can be evaluated through a budget variance analysis. A similar process can occur at the next level up.

In Figure 2, resources from each expenditure area (column totals) are allocated to cells via planned percentage of effort. Figure 3 shows the "dollarized" result obtained by multiplying the column total by the percentage of effort assigned to each cell. The additional summary column, total, becomes the entry in the matrix for the whole manufacturing group in Figure 1. Figure 4 shows that summary in percentage terms, allowing a comparison across departments of effort deployment.

When the percentage amounts are converted to dollar figures and summed across the rows, the result is Figure 1. This matrix provides an expected expenditure for each strategic objective in the firm. Such matrices can be used for a variety of analyses. One can compare allocations to the priorities that the firm has established or do time series analysis to examine trends. Results can be compared with spending in order to determine cost/benefit viability or compared within and across columns to determine efficient "deployments" of effort. For example, if the dollar amount spent in Work Center 1 for quality is higher than that spent in engineering, and quality is poor, perhaps some reallocation of effort in design is indicated.

Analyzing the relative expenditures in columns that are primarily devoted to support functions also can be productive. For example, analysis of the amounts spent by the computer systems group for each of the rows might lead to a better understanding of the firm's use of computing resources. Similarly, if the relative amount of effort spent by industrial engineering on quality has not changed, even though the company has decided that a serious quality gap exists between its products and those of its competitors, something is wrong in the company's allocation. Finally, if such support function managers cannot determine how their efforts relate to goals, that, in itself, signals a problem. The point is that the CAGS approach encourages direct examination of overhead costs and activities, not overhead allocations.

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